FERTILITY.

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1881.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS

The substance of the following pamphlet has appeared in a series of letters recently published in the 'Agricultural Gazette.' The subject has been already treated in a more scientific manner by Dr. Gilbert in his opening address as president of the chemical section of the British Association last year. My object has been to bring out in a different form, adapted for a more extended circle of readers, certain conclusions, the result of investigations at Rothamsted, which at the present time have a most important bearing on practical agriculture.

J. B. LAWES.

Rothamsted,
June, 1881.

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We learn from geology that the world which we inhabit has passed through great changes, extending over vast periods of time. Compared with these periods, the existence of man in the world, however far back it may ultimately be traced, is quite a recent occurrence.

Whatever difference there may be in our views respecting the origin of species and the law of development, there can be none respecting the necessity of a creation of vegetable life, previous to that of man and animals as they now exist. They both derive their food from plants, and even the carnivoræ are indirectly dependent upon vegetation, as the flesh which they eat is formed by plant-eating animals.

Amongst the many changes produced upon the earth by man, those that affect vegetation are full of special interest. In our study of the lives and habits of animals, some of their operations appear to be the result of reason rather than instinct. For instance, the storing up of food for a winter supply

appears to be an act of intelligence and forethought. It may be observed, however, that, previous to the appearance of man, the vegetation as it existed upon the earth furnished the sole supply of food to every living creature. It was reserved for the higher intelligence of man to destroy this existing vegetation, and, in its place, substitute one more suitable to his wants.

At what period of the history of the human race the cereal grains first formed part of their food, will probably never be known; there is, however, evidence to show that grain was used by pre-historic man, and at the present time, in one form or another, the cereal crops constitute the greater portion of the food of the world's population.

So entirely are we dependent upon the seed of these annual plants, that if we could imagine a year in which no crop ripened its seed throughout the world, the result would be that the greater part of the population would starve to death. At the same time so artificial are the circumstances attending the growth of these plants, and so entirely is their existence dependent upon the care and attention of man, that without such care they would become again as rare as when man discovered their valuable properties.

Perennial vegetation is the natural vegetation of the earth, and so great are the efforts of Nature to assert her rights, that if we allowed one of our fields

of corn to shed its seeds, and the same thing to happen as regards the annual weeds—which grow so abundantly among the corn owing to our destruction of their natural enemies the perennial weeds—it would only be a question of a few years, more or less, before the soil of the field thus left to its fate, would be again covered with perennial vegetation; while the annual plants would either be entirely extirpated or only exist as rare specimens.

Although man can live upon food which does not contain starch, still it may be said that the daily want of every human being, from the time he can crawl until he goes into his grave, is so much starch. It constitutes the great bulk of the daily food of those who labour in all countries, and it is never absent from the diet of the wealthy, although their table may be covered with dainties furnished from every quarter of the globe. The cereal grain crops are the great starch-producing plants; the potato, which has on this account become a portion of the daily food of many nations, being the only other plant that can at all compare with them in this respect.

The vast deposits of coal found in various parts of the world inform us that the earth has been covered with vegetation, which has been destroyed and renewed over and over again. The agriculturist has no direct interest in this vegetation, beyond the fact of its furnishing him with a supply

of fuel, and a small amount of manure. It is far otherwise, however, with the vegetation that exists, or has existed upon the earth since the last great geological changes took place, and the continents and seas assumed somewhat the position in which we now find them.

The natural vegetation of the earth, whether it be of forest, moor, or pasture, is chiefly perennial, and produces woody matter not adapted for food, or with the food ingredients so mixed up with indigestible matter as to be quite unfit to be acted on by the human stomach. Unless, therefore, man calls in the aid of an animal stomach to do the work of separation for him, his first step must be to destroy this existing vegetation.

We have been so long accustomed to cultivated fields in this country, that we can hardly realise that they ever existed in any other state than that in which we see them at present. In the United States, however, millions of acres are being brought into cultivation every year. We see there, agriculture advancing—to use an expression which our greatest statesman applied to our commerce a few years ago—by leaps and bounds, so that our British farmers seem in a fair way to be swamped by the competition; while in Ireland, and in India, we have a population pressing so severely on the resources of the soil, as to make the question of food one of paramount importance to our statesmen. I think, therefore, that the question

"What is fertility?" is not otherwise than an appropriate one to consider at the present moment, and with this view will now proceed to make some observations on the subject.

If we took a quantity of rocks, such as we find in various parts of the earth's surface—granite, slate, quartz, limestone, &c.—and, after grinding them to different degrees of fineness, were to mix them together in different proportions, we could from the known composition of these various rocks, produce soils which would contain the most important mineral constituents of plant food in very different proportions. Assuming that we purposely made one soil as rich as we could in this food, one as poor as we could, with two others in intermediate stages, and we then left them exposed to the ordinary influence of sun and rain—I am here assuming the experiment to be tried upon several acres, and the artificial soil to be several feet deep—we should find that the seeds of plants carried by the winds and other agencies would spread and grow upon these soils with very different degrees of rapidity; and, assuming that we were able to watch the process for thousands of years, we might see several remarkable changes in the character of the vegetation. The surplus of the winter store of acorns laid up by a mouse might give rise to a forest of oaks, thick enough to destroy all the previous vegetation of grass; and again an accidental fire or a hurricane might

sweep away the forest vegetation, to be replaced by growth of some other kind.

The character and amount of the vegetation would differ greatly on the different soils, and the largest amount would be found on the soil where the plant could get the largest amount of food.

There being no carbon or combined nitrogen in the soil, the first plants would be entirely dependent upon what they could obtain of these substances, directly or indirectly, from the atmosphere. Rain-water always contains ammonia, and the plant and the soil may condense a certain further amount from the atmosphere[1]; but growth, even in the soil richest in mineral food, would at first be small, as the decomposition of carbonic acid and fixation of carbon would be limited by the amount of combined nitrogen which the plant could obtain from the sources mentioned above; and it would be much greater where the most abundant mineral food existed, as every particle of the available nitrogen would be there used up; while where there was less mineral food, some of the combined nitrogen might pass through the soil and be lost.

Each year a certain portion of the vegetable growth dies off: leaves and branches fall, and portions of the roots decay. Part of the organic portion which falls upon the surface of the ground, returns again to the atmosphere, but a certain part remains, and added to that which decays underground, becomes

available for future growth. The atmosphere of the soil, which at first differed little from that which exists above it, becomes highly charged with carbonic acid, which decomposes the minerals in the soil, and thus, year by year, more and more of the nitrogen, collected by each generation of plants, becomes available for the generation that succeeds it.

This carbonaceous organic matter, under the general term Humus, was considered by the chemists in the early part of the present century to be the main source of fertility. The late Baron Liebig turned this idea into ridicule, and the word has almost been forgotten.

Under the term humus I include all those organic compounds in the soil which have gone through certain stages of decay since they formed parts of living vegetation. These compounds may be distinguished from living vegetation by their containing a larger proportion of nitrogen to the carbon.

Upon the greater number of ordinary soils the proportion of both carbon and nitrogen becomes less and less as we penetrate below the surface, consequently these substances must have had their origin in vegetation which had once grown upon the surface. Some soils which are called alluvial possess a subsoil fertility which appears to have been a deposit derived from the remains of vegetation washed from other soils. Fertility is, therefore, due to the organic residue of previous generations of plants, mixed with certain

mineral substances, the most important of which are phosphoric acid and potash.

As the annual rainfall in most parts of the world is in considerable excess of the evaporation, it is evident that those substances which I propose to designate as the stock of fertility in a soil must exist in a comparatively insoluble form, or they would have been washed away.

In regard to potash and phosphate of lime, we may assume that they are dissolved by secretions from the plant when the roots are in direct contact with them. Humus may be taken up in a similar manner, and by some plants more readily than by others. Still, it is not until the nitrogen of the humus has assumed the form of nitric acid that its full effect upon vegetation is realised.

A short time ago Schlösing proved that nitrification was due to the action of a minute organism, which abounds in our soils. Under favourable conditions of temperature and moisture, nitric acid is produced with great rapidity; it has been proved in regard to the yeast plant (which converts sugar into alcohol and carbonic acid) that, like our ordinary crops, its growth depends upon a supply of mineral food. We know the nitrifying plant cannot carry on its work unless it is furnished with alkaline substances to neutralise the nitric acid formed. If, as may be the case, it requires alkalis and phosphates, we can explain why it is that the water

passing through peaty soils does not contain nitric acid.

Under whatever conditions the nitric acid may have been produced, there is no doubt, however, that its efficacy as an agent of vegetable growth is very great; in fact, a farmer is often willing to give the value of a bushel of wheat for 5 or 6 lbs. of nitrogen in this form. Every one must have noticed how difficult it is to keep land free from weeds; even our roads and gravel walks, if left undisturbed, soon become covered with vegetation. As a further illustration I may mention that upon the platform of the station which I frequent a number of minute holes exist in the asphalt, owing to the escape of small bubbles of air when it was in a plastic state, and in each of these minute holes a small plant has taken up its residence.

When the pressure of the atmosphere was first discovered, but before the cause was known, the philosophers of the day pronounced that it was due to Nature's abhorrence of a vacuum. A few years ago no more rational explanation could have been given for the persistent efforts of Nature to cover the earth with vegetation; but modern science has thrown more light on the subject. Boussingault placed some garden soil, rich in organic nitrogen, but containing very little nitric acid, in a closed glass vessel: it was moistened and exposed to a temperature favourable to nitrification, and was frequently

stirred: at the end of a few months this artificial fallow had lost one-half of its carbon, and a formation of nitric acid had taken place, which, if calculated on an area of an acre, would have been equivalent to several hundred pounds. In an ordinary winter most of this nitric acid would be entirely washed out of the soil. We learn from this that vegetation prevents the escape of nitric acid, and stores it up as food products; then finally, when vegetation decays, it assumes the form of insoluble compounds such as humus.

Independently therefore of the removal of food products from the soil, which is the main object of cultivation, the constant stirring of the soil brings into activity more of the inactive ingredients, while the cultivation of annual plants—by leaving the soil so long without vegetation—is followed by large losses by drainage.

We now come to the question, if fertility is the result of accumulations, due to previous generations of plants, what is exhaustion?

In this term I intend to include all those operations of agriculture, the result of which is to reduce the capital stock of fertility which the soil contained when first brought into cultivation. The aim and object of agriculture is directed to this end: and that the complete exhaustion of the soil is not sooner effected is not due to any moderation on the part of the cultivator, but rather to the resistance which the

self offers to the too rapid removal of its es.

Rothamsted, portions of seven fields have under careful experiment, for periods extending, in one instance to forty, and in all to more than twenty years. In addition to numerous experiments upon other parts of the farm, we have about 50 acres devoted to the continuous growth of the ordinary farm crops, both separately and in rotation.

In all the Rothamsted experiments, portions of each field have received no manure of any sort; while upon other portions the manures we apply are used continuously upon the same plots of land, and we thus get some idea of what is going on in the soil. Although not quite so interesting to practical farmers as some of our experiments, those in which the crops are grown continuously without manure of any sort, require to be very carefully studied; for, as the claims of tenants for unexhausted fertility are becoming more and more recognised, the time seems to have come when some effort should be made to draw the line between the natural fertility inherent in our soils, which is given in exchange for rent, and the additional fertility which the tenant brings upon the land at his option, but cannot altogether remove.

Many think that the original fertility of soils which have been in cultivation for centuries, has long since been exhausted; and that the crops now grown are due to the manure applied by the existing cultivator.

Before going into this question, on which I may have more to say later on, I will attempt to give some idea of the changes which have taken place since the land at Rothamsted was first brought into tillage, to the date when our experiments commenced; and again from that period to the present time.

I have before mentioned that all land was originally under vegetation, which was almost entirely perennial. In the earliest days of agriculture of which we have any record, the system adopted appears to have been to break up the woodland, moor, or rough pasture and take several corn crops in succession, until the produce did not repay the cost of the seed and cultivation; the land was then allowed to rest for some considerable time, when the same process was repeated. The exhaustion of the soil under this system would not be very rapid.

At what period my land was first brought into arable cultivation it is impossible to say, but at Rothamsted I have records which prove that wheat, and other corn crops were grown 250 years ago upon the same fields which are now under experiment; there are, however, no data to show how often a field was cropped in succession.

Speaking of a period much more recent than that to which I am referring, Macaulay says that the total yield of grain in Great Britain did not exceed 5,000,000 qrs. annually. Whatever might be the date at which

my fields were first brought into arable cultivation, it is probable that they were previously in a state of rough pasture with trees interspersed. On the south-east side, and forming part of the field, which has been under wheat experiments since 1844, there is rather more than an acre of pasture left, and extending the whole length of the south-west side of the same field there is also an unusually broad strip of grass, whence probably the field derived its name of Broadbalk. Adjoining the wheat field is an enclosure containing a few acres of pasture, which, judging from the character of the trees growing upon and close by it, has probably been undisturbed for centuries, and possibly may never have been in arable cultivation at all.

The soil of the pasture land in Broadbalk field, as also of that in the adjoining enclosure, have been submitted to careful analyses, and we find that they do not differ materially from each other. After removing all vegetable matter, roots, &c., amounting to several tons in weight per acre, the first 9 inches of the finely sifted mould contain 5700 lbs. of nitrogen, while the second 9 inches contain about 2500 lbs. more. In these experiments the analysis was not carried below 18 inches, but in another plot of pasture, of the same character, a short distance off, the analysis has been carried to a depth of 54 inches from the surface. Between 18 and 54 inches the nitrogen gradually declines; still, the quantity

between these two latter depths would amount to about 5000 lbs. per acre, or about 1 lb. to every cubic yard of soil. If we assume the surface soil to be 9 inches deep, we have 5700 lbs. of nitrogen in the surface soil, and 7200 lbs. below it, making altogether nearly 13,000 lbs. per acre within reach of the roots of some of our agricultural crops. This nitrogen, with certain minerals, forms the stock of fertility which could be drawn upon by those who first commenced growing arable crops.

The Rothamsted experiments had been carried on for some years before we attempted to sample and analyse soils, consequently the composition of my arable land, at the time it was first brought under experiment, is not based upon actual analyses; still, the analyses made since that period in the various fields have been so numerous that it is not difficult to fix, within some reasonable limits, the original composition of the surface soil. I am disposed to estimate the amount of nitrogen in the first 9 inches of the Broadbalk soil in 1840 at about 3000 lbs. per acre; the second 9 inches at between 2100 and 2200 lbs.; this would give a total stock of 5100 to 5200 lbs. per acre, which shows the very considerable reduction of about 3000 lbs. per acre in the amount of nitrogen contained in the arable land, as compared with that contained in the pasture.

I may observe there is nothing new in the fact that pasture contains a much larger stock of fertility for

the crop to draw upon than arable land. Mr. Caird, for instance, while discussing the possibility of our foreign supply of wheat coming to an end, refers to the stock of fertility existing in our pastures which might be rendered available. It is also further confirmed by the saying that the conversion of pasture into tillage makes a man; and if, as is certainly the case, the accumulation of the lost nitrogen in the soil is necessary to the existence of a pasture, we can readily understand that the converse process of converting arable land into pasture might be said to break a man. My present object, however, is to attempt to give some definite form to the term fertility; it is true I have only brought into my calculation one of its elements; but it will be seen, as we go on, how very important this element is.

There is every reason to believe that the nitrogen in the soil which lies below the depth of 9 inches is available for vegetation, still the amount of roots which penetrates below this depth is so small, as compared with the number of those that feed nearer the surface, that any reduction which may occur in the amount of the nitrogen at the lower depth must be comparatively small, and difficult to estimate by analyses unless periodically taken at very long intervals of time; the measurement of such changes as may occur must therefore be left as a legacy to a succeeding generation.

Since 1839 the Broadbalk field has grown one crop of barley, one of peas, one of oats, and thirty-eight crops of wheat. In 1846, 1856, 1865, 1868, and 1879, the soil of various parts of the field was analysed, and it is from the data thus furnished that my estimates are made.

In a lecture delivered by Dr. Gilbert in the South Kensington Science Conferences in 1876, he gave in a table the amount of nitrogen removed in the unmanured produce of wheat and straw as follows:—Eight years 1844–51, 25 lbs. per acre per annum; twelve years 1864–75, 16 lbs. per acre per annum.

In a recent paper on the home produce, consumption, imports, and price of wheat, we estimated the annual decline in the yield of the unmanured wheat crop at from one-third to one-quarter of a bushel per acre per annum. This in forty years would be equal to from 10 to 13 bush. as the reduction of the crop due to exhaustion.

With regard to the nitrogen in the soil, each analysis shows a reduction in the amount per cent. as compared with that which preceded it. The difficulty consists in fixing the actual amount of such reduction. I am disposed, however, to estimate it at from 1000 to 1200 lbs. per acre during the forty years, which would be considerably more than the amount of nitrogen carried off in the crops of wheat.

From what I have previously said respecting the production of nitric acid, and its liability to be washed

out of the soil by drainage in the absence of vegetation, it might be expected, in regard to the continued growth of a crop like wheat—which ceases to collect food from the soil early in the summer—that considerable losses would have taken place by such drainage in the earlier periods of the experiment. Unfortunately, however, we had no drainage water collected from the field at those periods. At the present time the composition of the drainage water of the unmanured land rather indicates that the loss of nitrogen by drainage is not more than what we might expect would be supplied by the rain-water falling upon the land.

To sum up this part of the subject, we have evidence of a very large loss in the accumulated stock of nitrogen, based upon the assumption that my land was originally pasture; there is a further large loss during the period in which the land has been under experiment and growing unmanured corn crops. The crops are declining; the amount of nitrogen removed in the crops each year is declining; and, further, a considerable reduction of the nitrogen in the first 9 inches, with an indication of a small reduction in the second 9 inches, is shown by different analyses of the soil itself.

The experimental plot to which I am about to refer received for the first few years an application of different mineral manures and salts of ammonia, the

amount of nitrogen contained in these manures being considerably in excess of that removed in the straw and corn of the crops of wheat grown by them. In the season 1852, therefore, when purely mineral manures were used alone, the land was in a better position, as regards the exhaustion of its nitrogen, than that from which twelve crops had been removed since the application of manure.

From 1852 to the present time, potash, soda, magnesia, and superphosphate of lime have been applied every year. The application of potash and phosphoric acid each year has been more than twice as much as the largest crops of wheat could carry off; and as these substances suffer very little loss by drainage, there must have been a considerable accumulation in the soil during the twenty-eight years of their application. Dividing the twenty-eight years into four periods of seven years each, we find that over the first seven years the mineral-manured land gave a produce of 3 bushels of dressed corn, per acre per annum, in excess of the crop grown on the permanently unmanured land. During the second period of seven years the excess amounted to 2 bushels annually; during the third period it was 1¼ bushel; and during the last period it was 1 bushel only more than the unmanured crop. The average produce over the whole period, calculated at 61 lbs. to the bushel, was, for the unmanured land, 12½ bushels, and for the minerals 14¼ bushels

per acre. It is probable that some unexhausted residue of the nitrogen, applied before 1851, may have been available for the crop grown by minerals alone during the early period; but even with this advantage, the amount of nitrogen removed in the produce of the mineral-manured crop, as given in Dr. Gilbert's South Kensington lecture in 1876, was, on an average of twenty-five years, only 22·1 lbs. per acre per annum, as against 19·3 lbs. taken off in the unmanured produce during the same period.

Under a most liberal supply of minerals, therefore, the soil and atmosphere combined have been unable to furnish 3 lbs. more of nitrogen to the crop, or to add to the produce more than 2 bushels of wheat per acre annually.

Analyses of the soil have not been made so frequently upon the plot, manured with minerals only, as upon the unmanured plot, but, as far as we can judge, the decline in the nitrogen is very similar in both cases.

My object in these pages is to trace out and explain the sources of natural fertility. I must, therefore, refer those who wish to follow out the subject at more detail, to our article on "Twenty Years' Growth of Wheat," published in the *Journal* of the Royal Agricultural Society of 1864, which showed most conclusively, that it only required an addition of some soluble compound of nitrogen, to the minerals used

in the experiment upon which I have just been commenting, to raise the produce of wheat to the highest amount which the season was capable of growing. I may add that we are now within three years of a second period of twenty years, when a further report may be looked for, to confirm and strengthen the previous conclusions.

I have gone very fully into the evidence of the sources of fertility, and the character of the exhaustion shown by the experimental wheat field, because of the great national importance of wheat as a crop, and because the evidence which this field affords regarding the general exhaustion of the soil, and the character of such exhaustion, appears to be very clear and distinct. I propose to treat the results obtained in the other experimental fields much more briefly, and merely point out their general bearing upon the fertility of the soil, and the nature of the exhaustion.

PERMANENT BARLEY.

The land devoted to this crop last received an application of dung in 1847; since then one crop of wheat, one of clover, and 31 crops of barley have been removed. Only one series of analyses of the soil has been made, therefore at the present time we have no record of the changes which are going on.

There are several marked distinctions between wheat and barley; the former is sown in the winter, the latter in the spring; the former requires a firm

ompact seed-bed, the latter, one of a light porous character; further, under the same conditions of climate, the crops may be differently affected, as was the case in 1880, when the wheat crop proved very indifferent, while the barley crop was most abundant: when, however, due allowance has been made for all such distinctions, we find that the character of the exhaustion in the field under barley is very similar to that in the field under wheat.

If we compare the produce of the unmanured barley during the first and second periods of the experiment, we find that the reduction in the latter—amounting to 7 bushels of grain and 4 cwt. of straw—forms one-third of the whole produce. On the plot which receives exactly the same liberal supply of minerals as the corresponding wheat plot, there has also been a decline of one-third in the crop, amounting to 10 bushels of barley and 5 cwt. of straw per acre. While, therefore, both the unmanured and the mineral-manured land has shown a proportional decline, the application of the minerals has enabled the barley to produce annually, during the whole period, 7 bushels more corn per acre than the plot which received no manure; this is considerably more than the difference between the corresponding plots in the wheat experiments.

PERMANENT ROOTS.

The experiments in roots commenced in 1843, and since that time, either white turnips, swedes, sugar-beet, or mangels have been grown every year except three, when three unmanured crops of barley were taken in succession.

On account of the different kinds of roots grown, and especially from the clearly ascertained fact that the soil and climate at Rothamsted were more adapted to grow sugar-beet or mangels than turnips, it is impossible to show the character of the exhaustion of the soil by the same mode of illustration as in the case of the wheat and barley crops. If we were to take the produce, for the last ten years, of the sugar-beet or mangel grown on the unmanured land, or even on the land receiving a large supply of minerals, and compare it with the crop of turnips grown, during any ten years, under similar conditions, we should show increased instead of diminished produce, and any conclusion drawn from this fact with regard to the state of fertility of the soil would be erroneous.

We shall be able to form a better judgment as regards the question of the fertility of the soil from the fact that, during the last ten years, the highest amount of produce obtained by a very liberal supply of minerals annually, has only been a little over 8 tons per acre.

The season of 1880 was exceedingly favourable for roots; the general verdict of farmers was that the crop was one of unusual magnitude, and yet the produce by the mineral manures was less than 6 tons of mangels per acre. The analyses of these roots have not yet been made, but the nitrogen they contain will amount to about 17 lbs. per acre. This is almost identical with the amount of nitrogen which Dr. Gilbert, in his South Kensington lecture, states was taken off annually for ten years, between 1864 and 1875, by the wheat crop which received a similar application of mineral manures. With a liberal supply of nitrogen added to the minerals, the crop last year in one instance exceeded 30 tons.

We have made a considerable series of analyses of the soils of the various plots, and have arrived at the conclusion that the soil, from which the roots manured with minerals have been removed, is poorer in nitrogen than the soil similarly manured which grows wheat or barley. The broad leaves of the root plant are said to obtain large quantities of nitrogen from the atmosphere. At the present time, under a liberal supply of all the necessary minerals, about 15 lbs. of nitrogen to the acre is all that our roots can obtain from soil and atmosphere combined. With these facts before us, we may assume that the large crops of roots, grown in different parts of Great Britain by means of mineral superphosphate, are due to the

amount of available nitrogen existing in the soil during the growth of the crop.

In order to measure the exhausting effects of any agricultural crops, and also the special character of the exhaustion, it is not only essential that crops should be grown continuously, both without any manure, and with various manures applied to the same portion of land without change; but also that some of the manures applied should grow full agricultural crops. These conditions have not been fulfilled with either of the two crops to which I am now about to refer, viz., beans or red clover.

Since 1848 a field has been devoted to the growth of beans, but with very partial success. After a few years the unmanured produce was reduced almost to nothing, and with no combination of artificial manures could we succeed in producing agricultural crops.

Part of this want of success is due to the character of the plant—beans send down strong, fleshy roots into the subsoil, while much of the food we apply as manure is deposited on the surface, and finds its way very slowly to the subsoil, even if it reaches it at all. The value of beans, therefore, as a rotation crop depends very much upon the natural fertility of the subsoil. Beans are grown more or less in every part of Great Britain, but in most of the counties the area under this crop bears so small a proportion

so that under other crops, that evidently their more frequent cultivation does not pay, and the growth of the crop itself partakes somewhat of the nature of an experiment.

In a few localities, where large tracts of alluvial soil or rich clays are found, beans are grown with success; but only one or two of the counties in Scotland grow any quantity, and in those the alluvial soil extends over a considerable area. Although the soil of our bean field has been submitted to analysis, the results, from the want of success in growing the crop, do not show whether exhaustion is taking place or not.

In our attempts to grow red clover continuously upon our arable land, we have been even more unsuccessful than with the beans. The crop has been grown, however, for twenty-five years on an unmanured but very rich garden soil, and we find by analysis that there has been a very great reduction in the stock of nitrogen in the soil, in consequence of the amount of this substance which—as well as minerals—must have been carried off by the removal of the crops, during this long period. The result of this experiment leaves very little doubt that the inability of our ordinary arable land to grow red clover, is due to a want of sufficient food in the soil, and also to the want of its proper distribution.

It would hardly have been anticipated that the grain crops could thrive better, and get more food

from a permanently unmanured soil, than roots, clover, or beans, which are known to act as restorative crops. Such, however, is the case in the unmanured rotation which has been under experiment since 1848.

When the experiments were commenced the field devoted to rotation was in much better condition than either the experimental wheat or barley fields, and yet in a four-course rotation which included turnips, and clover or beans, alternating with wheat and barley, the evidence appears to show that a greater produce of grain would have been taken from the land by the continuous growth of cereals, without the alternation of restorative crops. The turnips after the first crop, when, as I mentioned, the land was in good condition, have ceased to be a crop at all, and with all the aid of the fine root-growing season of 1880, were incapable of forming a bulb. The average of six crops of beans was barely 13 bushels, and a red clover crop, taken after an interval of twenty-five years, was very small. The barley, however, has averaged 34 bushels, and the wheat 27 bushels, per acre during the whole period, and it is quite certain that if wheat had been grown continuously during the twenty-five years, it would have produced more than 14½ bushels every year; or if barley had been grown continuously, it would have produced more than 17 bushels annually.

This property which our cereals possess of extract-

ing nourishment from a soil, where other crops are unable to do so, will be an important consideration when we come, later on, to estimate the exhaustion of the soil of those countries which compete with us in the growth of corn.

By the employment of a mineral superphosphate every four years the root crop has been largely increased, and when the roots have been carried off the land, the succeeding barley crop has been very much less than that grown upon the permanently unmanured land, where a very much smaller root crop was carried off over the whole period of the experiment.

The amount of nitrogen removed in the crops where the superphosphate was used, has been greater than that removed from the unmanured land, and the crops in both the experiments are declining; the analyses of the soil of the two experiments also show a decline in the nitrogen; but still we have no clear evidence to show upon which of the two experiments, the crop, or the nitrogen in the soil is declining the most rapidly. It would probably have been supposed that a period of thirty-two years would have been sufficient to establish a fact of this nature, but such has not been the case. There have been only eight rotations in the period, and each crop has therefore been grown only eight times. Owing to the great fluctuations in our climate these eight crops are not sufficient to measure with accuracy the rate of de-

cline, more especially as the last few seasons have been exceptionally unfavourable to the growth of corn.

I have already said that my permanent pasture contains a much larger proportion of nitrogen than the arable land. This excess probably amounts to more than 2000 lbs. per acre in the first 9 inches from the surface, without taking into account the great quantity stored up in the turf and roots. Under these circumstances we might expect that mineral manures would produce a more beneficial effect upon pasture than upon arable land, and such has proved to be the case, as, during the twenty-five years of experiment, the produce of hay grown by a liberal supply of alkalies and phosphate, has not only been very much greater than the produce obtained upon the permanently unmanured pasture land, but alsc, up to the present time, it has shown no perceptible decline. The grass is pale in colour, and shows none of the luxuriance and vigour which we find in the herbage where there has been an application of nitrogen, as well as of minerals; still the removal of about 46 tons of hay, containing more than 1000 lbs. of nitrogen, without any fresh application of that substance to the soil, is a very interesting fact.

No general analyses of the soil of these experiments took place until they had been carried on for twenty years; consequently, its composition when the experiments commenced is unknown. But a few selected

plots were analysed in 1870, and in 1875—the twentieth year from the commencement—several samples were taken to the depth of 54 inches on each experimental plot of the whole series.

The amount of nitrogen in the first 9 inches of the mineral-manured soil is found to be considerably lower than that in the unmanured soil. While, however, the hay removed annually from the unmanured land has not much exceeded 1 ton per acre, the hay removed from the mineral-manured land has amounted to rather more than 1¾ ton per acre.

To institute an exact comparison between the loss of the nitrogen in the soil of the mineral-manured and unmanured land, and the amount of nitrogen carried off in the two crops of hay, would only mislead, as it would be assuming the possibility of a minute accuracy in measuring the results, which, from the nature of the circumstances, would evidently be impossible.

I have now passed briefly in review the general bearing of the Rothamsted experiments, as regards the fertility and exhaustion of soils. Those who have taken the trouble to follow the results given in the preceding pages, can hardly fail to have noticed how very much the growth of our crops is dependent upon the stock of nitrogen stored up in our soils; and, as the crops and soil in other localities are, more or less, exposed to the same climatic influences as the crops and soil at Rothamsted, we may fairly conclude

that such crops are, in like manner, dependent for their growth upon the sources of fertility stored up in the soil.

I will not here pronounce an opinion with regard to the various ways by which the plant, or the soil may obtain nitrogen from the atmosphere; still, giving them all their full value, it cannot be denied that some of our crops have become much reduced for want of nitrogen, even where there was still a very considerable stock in the soil.

It would appear, therefore, that while our crops can obtain all the carbon they require from the atmosphere; for nitrogen, they are far more dependent than has generally been supposed, upon the stock which has been accumulated in the soil, or that which has been applied in manures.

Except at Rothamsted I am not aware that any attempts have been made to procure sufficiently representative samples of soil before they are submitted to analysis. The usual method has been, to take *about* a spadeful of soil, which has generally been considered a sufficiently accurate measure for the purpose. With us the process of taking the sample is quite as important an operation, and one requiring quite as much care and skill as that of making the analysis.

Although we generally take our samples in successive 9 inches, still we have occasionally taken them at each 3 inches in depth, and have found

ıat considerable differences exist in the quantity ſ nitrogen as each 3 inches receded from the ırface.

A question then naturally arises as to whether the ;othamsted soil, as compared with other soils, is rich r poor in nitrogen. It is hardly possible to omit all ›ference to this point, but at the same time, for the ›asons which I have given above, a very considerable ıargin must be allowed for error, arising from the nknown depth at which some of the various samples hich I am about to bring forward for comparison ıay have been taken.

Professor Schmidt, of Dorpat University, has made very elaborate series of analyses of the celebrated ;ussian black soils, which are said to be the most ›rtile in the world. These soils have also been nalysed by Dr. Voelcker, for Mr. Butler Johnstone, ho owned an estate in that part of Russia where ıey are found. There is a general agreement between ıe two series of analyses; I have however adopted ıose of Professor Schmidt, as he gives the depth ; which his samples have been taken, and the ımplings themselves have also been carried lower ɔwn in the subsoil.

In these analyses no attempt has been made to stimate the average quantity of nitrogen per acre; have therefore been left to the alternative of either iving the percentage of nitrogen in the soil—which ɔnveys no fact to a non-scientific reader—or of

adopting some estimate as a basis of the weight of the soil itself.

It would be a great mistake to suppose that these Russian black soils partake in any way of the character of the peat soils of Great Britain, which are very deficient in mineral matter. In Russia the surface of the black soil, richest in vegetable matter, contains also 84 per cent. of mineral matter; and usually the surface soil contains 90 per cent., and the subsoil from 90 to 97 per cent. of minerals.

I estimate that the richest soil in the series might contain, within 3 feet of the surface, from 40,000 to 44,000 lbs. of nitrogen per acre.

The Rothamsted pasture soil, within the same depth, contains from 10,000 to 11,000 lbs.; and the arable land from 8000 to 9000 lbs. of nitrogen to the acre.

Between 1 foot 10 inches and 2 feet 8 inches, the Russian soil contains more nitrogen than is contained in the surface soil of the Rothamsted pasture; and from six to seven times as much nitrogen as is contained in the Rothamsted soil at the above depth.

Another Russian soil, which was sampled at 9 inches from the surface, gives 10,700 lbs. of nitrogen per acre, while the second 10 inches give more than 4000 lbs.; but, below this depth, the amount of nitrogen is not greater than that found at the corresponding depth in the Rothamsted soil.

In one analysis it is stated that white chalk was

›und at 14 feet from the surface; in another analysis f soil, taken from arable land, the nitrogen in the ırface soil is not higher than that found in the rable land at Rothamsted. Whether this is due to ‹haustion by cropping, or to the fact of its being aturally a less fertile soil, there is no evidence to ıow. I may mention that all of the Russian soils nalysed by Dr. Voelcker are exceedingly rich in itrogen.

In the *Journal* of the Royal Agricultural Society f 1868, Dr. Voelcker gives some analyses of soils, ıken from the arable land of a farm in the neighbour-ood of Leighton Buzzard. The mean of the analyses f two different samples of soil gave the amount of 428 lbs. of nitrogen to the acre in the first 18 inches 'om the surface; this would be about 3000 lbs. per :re more than the nitrogen in the arable land, taken) the same depth, at Rothamsted. Agriculturists 'ho know the two districts would readily admit that he soils in the neighbourhood of Leighton Buzzard 'ould be more fertile than those of the district in hich I live.

In 1858, Dr. Voelcker analysed samples of four rairie soils from the State of Illinois, brought over y Mr. Caird, from whom I have ascertained that ıey fairly represent the character of the land to the epth of 1 foot from the surface. To this depth they 'ould probably contain from 7000 to 10,000 lbs. of itrogen per acre.

No one has devoted so many years to the analysis of soils as M. Boussingault, and I shall close this part of my subject by a reference to some analyses made by him.

His farm is situated at Bechelbronn, in Alsace, and he gives an analysis of the soil of a wheat field there, which resembles very closely in character that of the soil in my district. It is also somewhat remarkable that the same five-course rotation has been adopted both in Alsace and Hertfordshire, the only distinction being that in Alsace the three corn crops comprise two of wheat and one of oats, while in Hertfordshire, barley takes the place of the second wheat crop.

Boussingault gives the following amounts of nitrogen per acre, in various soils collected by him in different parts of the world, the calculation being made for a depth of 17 inches from the surface:—Argentan, rich pasture, 25,650 lbs.; Santarem, cocoa plantation, 32,450 lbs.; Rio Cupari, rich peat mould, 31,250 lbs.; Rio Madeira, sugar field, 5500 lbs. per acre.

In the early days of our experiments it was thought by some that the continuous growth of from 14 to 16 bushels per acre of wheat upon unmanured land was due to some unusual fertility in the Rothamsted soil. The evidence I have brought forward, however, so far from supporting this view, simply shows how little was then understood as regards the capacity of

an ordinary soil for growing continuous crops without any manure.

To sum up this part of the subject, it may be said that upon the land where continuous crops were grown without any manure, clover, beans, and roots, which are generally considered to restore the fertility to land exhausted by corn-growing, have declined more rapidly than the cereal grain crops; that a liberal supply of mineral manure, while it has added considerably to the produce of some of the crops, has not prevented their decline; that upon an unmanured four-course rotation, where all the produce is removed, the two crops of grain, grown in the rotation, do not give a larger produce than the continuous grain crops, grown during the same period on continuously unmanured land; that, in a rotation where mineral superphosphate of lime has been used, the root crop has been largely increased, and more nitrogen has been carried off in the produce than from the permanently unmanured rotation; but though the produce of both is declining, the evidence, up to the present time, is not sufficient to show on which of the two experiments this decline is proceeding the most rapidly. Lastly, that the general character of the analyses of the soils which have been made at different times, tends to confirm the conclusions just given, and to show a decline in the stock of nitrogen.

The experiments on pasture differ from those upon the arable land in the following important particu-

lars :—The produce of hay under a liberal supply of mineral manures has been greatly increased, and the amount of nitrogen removed has been very large; but at the end of twenty-five years there is no evidence of any decline in the produce.

It is true that the nitrogen in the surface soil of the pasture land shows a considerable decline, but with this exception there is nothing absolutely to prove that the atmosphere has not been the source of the nitrogen removed in the produce.

GREAT BRITAIN.

When we come to the application of the results given in the foregoing pages to the general agriculture of Great Britain, it is hardly possible to avoid the conclusion that, in most cases, profitable agriculture involves a slow but continuous exhaustion of the soil.

In the earliest stages of our agriculture, only the more fertile soils were cultivated; little, or none of the produce was returned to the land as manure, and long periods of rest intervened between one series of corn crops and another.

As population increased, land became more valuable, and the increasing wealth of the country enabled the people to consume a larger amount of animal food: the periods of rest were shortened, and fallow crops, such as roots and clover, were introduced.

In the production of meat, a very large proportion

of the soil-constituents of the food consumed by the animals would be returned to the land, and, in consequence of this restoration of fertility, there would be less exhaustion of the soil.

In certain districts of Great Britain there are soils so light, that they contain, in their original state, but a very small stock of natural fertility, and the crops they grow depend mainly upon that which is imported at the expense of the cultivator. There are also certain heavy soils which are very highly farmed; but, with these exceptions, it may be said of the existing system of agriculture in this country that, as regards relation of landlord and tenant, rent is paid for the right to remove, without restoration, a certain amount of the stock of fertility in the soil.

The various restrictions introduced into leases, covenants, and customs were evidently devised for the purpose of limiting, as much as possible, the removal of this stock of fertility; but from the complete ignorance which prevailed with regard to the ingredients of which it was made up, the restrictions were confined to such crops as experience seemed to show were especially exhausting to the soil.

If, as I have endeavoured to prove, the stock of nitrogen in our soils is one of the main sources of their fertility, the question arises—How are we to explain the benefits of the various operations of agriculture, such as draining, fallows, liming, tillage of all kinds, and the use of mineral manures, except by the

fact of their being so many means of liberating and utilising the stock of nitrogen in the soil?

Many of these operations are said to increase the stock of fertility; and that they do increase the *produce* of the land must be evident to the commonest observation; but it is at the expense of the stock in the soil; and they would be more correctly described as processes for turning to account the existing, but dormant elements of fertility contained in the land.

We may thus in a certain way compare the fertility of the soil, to the coal in a mine: neither the one nor the other is of any value until it is turned to some useful purpose, and this object cannot be attained without a diminution of the original stock. So much, indeed, is a reduction of this stock an essential to the profitable cultivation of many soils, that, if we could imagine a heavy clay to exist which did not supply any of the ingredients of plant food, it is doubtful whether its arable cultivation could be profitably carried out.

The natural fertility existing in a soil is cheaper than imported, or purchased fertility; and it would in fact be found more profitable to pay rent for a fertile heavy soil, than to farm unfertile heavy land rent free.

When a farmer increases his crops by means of such purchased manure as soot, or nitrate of soda, he estimates the profit of the operation by the increase of the crop alone. If his land would yield a crop of

wheat worth £8 without the purchased manure, and by the expenditure of 20s. the value of the crop was raised to £10, he would consider the operation had given him a profit of £1, as all the ordinary expenses connected with the growth of the crop are charged against the produce derived from the natural fertility of the soil.

In the district where I live the land is cultivated on a five-course shift, and the crops which are grown, and sold off the land, would cost more to produce by the means of purchased artificial manures, than the sum which the tenant, under the above system of cultivation, pays for them in the rent; or in other words, as far as regards the production of the crop, the landowner sells his fertility cheaper than the manufacturer of manure could supply it.

The employment of manure of some sort is universal in this country; and so far as such manure consists of ingredients derived from crops that have been grown upon the farm, it retards and reduces the amount of exhaustion. Large quantities of cattle foods are also imported and used as manure; but large as the amount of imported cattle food may appear, it will be found that its consumption is confined to a comparatively limited area, and that it has but little influence on the general fertility of the country at large. As a proof of this fact I may say that the addition of only 1 lb. of nitrogen per acre to the 31,000,000 acres of cultivated land in Great

Britain, would require an import of about 500,000 tons of corn and cake, and the consumption of the country does not reach this amount. Even if the capital were forthcoming to carry out generally a system of high farming, a supply of purchased fertility, large enough to meet the increased demand, could not be obtained except at a price that would prohibit its use.

The evidence brought forward, in regard to fertility and exhaustion, enables us to comprehend somewhat more clearly the distinction between the fertility which is part and parcel of the soil, and that which is brought upon the land by the capital or the tenant.

There is still, however, before those who may be called upon to decide such questions, the very difficult task of ascertaining how much of any imported fertility still remains in the soil, and is available for future crops.

In the face of the increasing competition with the agriculture of the world, it is hopeless to bind the tenant's hands or cripple his energies by the restrictive covenants of a bygone age; and it would certainly be desirable, with the prospects of compulsory legislation on this subject, that the interests of both the landowner and the tenant should be more clearly defined.

If, at the commencement of occupancy, a brief agreement could be drawn up between landlord and tenant, to define the amount of fertility which the

latter was entitled to remove in exchange for his rent, the task of any arbitrator or judge, called in to decide between conflicting claims, would be made lighter.

THE UNITED STATES.

We are sometimes told by enthusiasts, that a liberal application of capital to the soil of Great Britain would enable us to grow all the wheat necessary to feed our population; there cannot however be any doubt, that in the cheap production of grain crops, the United States farmer possesses advantages which ought not to be either overlooked or despised.

First of all, and this is a most important point, the United States farmer himself is usually well educated and intelligent; he is both owner and occupier of the soil, and does as much as possible of the work of the farm himself, employing for the purpose the most improved labour-saving machinery; he is lightly taxed, has cheap modes of transit, and, above all, is in possession of an almost unlimited extent of untouched fertility. These circumstances all combined reduce the cost of growing corn almost to a minimum, and the result enables him to deliver his wheat at the doors of the owner of the land in some parts of Great Britain, cheaper than it can be raised in the adjoining fields. In a word, they enable him to regulate the price of grain throughout the world.

In my remarks upon the agriculture of Great

Britain, while assuming that, with comparatively few exceptions, it is carried on by a process of soil-exhaustion, I have pointed out that this exhaustion is greatly lessened by the production of meat and the use of manure.

I propose now, for the sake of argument, to consider the agriculture of the United States as carried on without any part of the produce being returned to the land in the form of manure, though I am perfectly aware that such a system of farming only prevails in certain districts of the States. How great indeed is the interest taken in all questions relating to the action of manures, and the exhaustion of soils, is fully proved by the large space allotted to these subjects in the numerous journals devoted to agriculture, as also in the records of the various experimental stations. I may add that this inquiry into what may be termed the science of agriculture is in remarkable contrast with the comparative indifference to the subject which prevails in this country.

It is not however the corn grown in the United States by purchased fertility, or even by the manures made upon the farm, that the British farmer need fear, as likely to compete with him. The danger lies in the vast stores of unused fertility, which constitutes the main wealth of the United States; and this fertility, as I have already pointed out, is very much cheaper than any derived from artificial or imported sources.

In the table below, drawn up by me some years ago, from the reports of the Department of Agriculture at Washington, will be found the amount of land in the United States under various crops upon an average of ten years, viz. between 1865 and 1875. So great has been the increase of land brought into cultivation since that date, that in 1880, 31,000,000 acres of wheat and maize alone had been added to the existing area.

The table gives the number of acres, in millions and parts of a million, of crops grown in the United States, on an average of the above period of ten years; the produce per acre; and the number of acres per cent. of the various crops:—

	Acres in millions and parts of millions.	Yield in bushels per acre.	Acreage per cent.
Maize	37.21	26	40.4
Wheat	20.50	12	22.1
Rye	1.31	13½	1.44
Oats	9.75	28	10.5
Barley	1.15	22¾	1.25
Buckwheat	0.72	18⅓	0.78
Potatoes	1.25	93½	1.36
Hay	20.35	1¼ ton	23.1
	92.24		100.

It would appear, from this table, that the cereal grain crops were grown upon rather more than three-fourths of the arable soil in the States. Upon an equal area in Great Britain, 46 per cent. of the land is under grain crops, and though we have no

statistics of produce in this country, I am disposed to think that more corn is grown, upon an equal area per cent. of arable land, in the United States, than in great Britain; that is to say that 76 acres devoted to grain corps in America produce more bushels of grain than the 46 acres so employed in our country.

The superior power possessed by the gramineous, as compared with other plants, of obtaining food from an unmanured soil—which was very clearly shown in the Rothamsted experiments—is confirmed by the character of the crops grown in the United States, where not more than 2 per cent. of the whole cultivated soil is occupied by crops which belong entirely to other orders; while in the hay crop, which comprises a great variety of different species, it is probable that the gramineous herbage largely predominates, timothy being generally quoted as the hay sold in the various markets.

With regard to the amount of nitrogen removed from the soil of the States every year, assuming that no part of the produce is restored, I am disposed to think that it might amount to about 30 lbs., or possibly a little more, per acre annually; supposing always that the crops grown do not exceed the amount given in the table. It is however, I think, certain that soils newly brought into cultivation would for a considerable time grow very much larger crops than these.

The idea that the fertility of these soils must shortly come to an end, or that grain crops cannot be produced at the present price, is altogether illusive.

The stock of nitrogen in immense areas of the United States soils must be competent to yield crops, equal to those given in the table, for a long time, and even when they begin to fall off, the residue of nitrogen may still be sufficient to allow of a fresh development of fertility by the employment of some cheap mineral manure, such as plaster or phosphate of lime; if this be so, the necessity of employing so costly a substance as nitrogen may not be apparent for two or three generations yet to come.

Before this period arrives the United States farmer will have become so well acquainted with the action of manures, that the profit or loss attending their application will not be a question of chance, but one subject only to the contingency of favourable or unfavourable seasons; a contingency from which it will be impossible to escape.

INDIA.

It is hardly possible to conceive agriculture carried on under conditions more completely different than those which exist in the United States and in India.

Every new emigrant who lands upon the shores of the United States is so much capital added to the wealth of the country. The average size of the farms

held by each person, according to the census of 1870, is 153 acres, of which one half is still unimproved. With this large area at his disposal the United States farmer yet does not hesitate to give up his holding and seek a new home, if by so doing he thinks that he can better his condition.

In India the Hindu increases and multiplies upon the spot on which he was born, and regardless of all economic laws, is apparently endeavouring to solve a problem which has frequently perplexed political economists, as to the relative increase of population and food.

This is what Mr. Hunter says in his lecture recently delivered at Edinburgh, and since published under the title of 'England's Work in India.' "We find 24,000,000 of human beings struggling to live off the produce of 15,000,000 acres, or just over half an acre apiece." So vast is the area of India, and so limited are the modes of communication, that while in some districts there may be a superabundance of food, in others the people may be dying of starvation. Mr. Hunter says that "throughout all British India, the average population is 212 persons to the square mile; or deducting the comparatively new and outlying provinces of British Burmah and Assam, it is 243 persons to the square mile."

In the United States there does not appear to be more than nine persons to the square mile. The process however of comparing the population of

various countries with the relative area, although useful so far as regards the question of statistics, is very misleading when brought forward to show the capabilities of a soil to support its population. For instance, if we applied to the agriculture of Great Britain the conditions under which the agriculture of India is necessarily carried on, that is to say if we estimated how much of the products of the soil—irrespective of all external sources of food or fertility—would be required to feed, clothe, and furnish with fuel each inhabitant, we should require to make considerable modifications of existing ideas on the subject.

The Indian Famine Commissioners say that "there are considerable parts of India in which the population is so dense that it presses closely upon the means of subsistence; and here, unless the existing system of agriculture is improved so as to yield a larger produce per acre, there is no room for any increase."

The last famine is said to have reduced the population of India by 5,500,000. In a country where the struggle to live becomes greater each year, we can readily understand that the removal of a certain proportion of the population must be a source of increased wealth to the remainder; and the Commissioners refer to a despatch of the Secretary of State, dated February 28, 1880, in which it is said "the facts testify to the remarkable power of the agricultural classes to resist and recover from the effect of unfavourable seasons."

No one can read the report of the Famine Commission without being convinced that every effort was made, and no expense spared to mitigate the effects of the famine; still there can be little doubt that the population is in excess of the food-producing power of the soil; and that, within certain limits, the removal of a certain number must add to the well-being of the remainder. The recovery from the effects of the famine might however have been less rapid had the lives of the 5,500,000 people been saved.

The conclusions which I have drawn from the Rothamsted experiments, as regards the fertility and exhaustion of soils, do not tend to lessen the difficulties with which our rulers have to contend in providing for the increasing population of India.

In Great Britain, although a fertile soil has a higher agricultural value than one of less fertility, still the relative value is not in proportion to the different amounts of fertility which the two soils can respectively yield up to the crops. Fertility drawn from all parts of the world, as also the advantage possessed by light over heavier lands as regards the expense of cultivation and as producers of meat, tends to lessen the distinction which would otherwise exist.

In India no external sources of fertility are available, and meat is far too costly a food for the consumption of the tillers of the soil. We are told that forests are disappearing, pasture is being broken up, cow-

dung is used for fuel, and that the area of waste land, whence was derived much of the manure ingredients which help to keep up the fertility of the continually corn-cropped land, is becoming every year less and less. We have therefore the fact before us that the Indian farmer has to obtain his food, clothing, and fuel, and pay the tax to the Government, out of the soil he cultivates: further, that the fertility which grows his crops comes from the soil alone, without any aid from external sources.

The tax is assessed upon the estimated value of the crops which the land will yield, and we might therefore expect to find that the fertility of a soil was the real measure of its value.

This is what the Commissioners say on the subject: "In Bombay the assessment is carried out by a separate department, on a very ingenious and complicated system. The land is broken up into blocks of from 5 to 40 acres each, which are separately assessed. The soils are classified on a uniform system according to their depth, and their faults, such as sloping surface, liability to inundation, or having a mixture of sand, clay, or gravel in the soil, all of which are sources of deterioration. The field which bears a maximum value is a level one of black soil, deeper than 1¾ cubits: this is the standard, valued at 16 annas. Every 'fault' and every quarter-cubit's decrease in depth deducts one or two annas or sixteenths from the valuation."

A Hindu cubit is, I believe, 25 inches; to be of the maximum value the black soil must therefore descend lower than 3 feet 8 inches. At Rothamsted our ordinary samples of soil are taken at the depth of successive 9 inches, though in a few instances we have taken them at 3 inches, but the Indian assessor measures fertility in still less proportion than our smallest gauge, for one-sixteeenth of 3 feet 8 inches is very little more than 2½ inches.

In referring to the Russian soils I pointed out that, in one case, where the black soil went down to the depth of from 3 to 4 feet, the nitrogen in the subsoil was as high as it is in the surface soil of my pasture land; while in other cases, where the black soil did not go down so low, the subsoil was not very different from that at Rothamsted.

Assuming the highest-valued soil in Bombay to have the composition of the richest black Russian soil, the number of pounds of nitrogen per acre in the lower quarter-cubits would amount to about 1600 lbs., while if the same area was taken in the districts where the black soil is not so deep, or upon the Rothamsted soil, the amount of nitrogen would be very much less.

With an absolute ignorance of all science, and merely by the experience derived from the growth of the crops, we have here an estimate of value placed upon every 2½ inches of soil to the depth of nearly 4 feet from the surface. Those who are disposed to ridicule

the idea of estimating the fertility of a soil by its stock of nitrogen will see how the value of such an estimate is confirmed by these results. It is true we have no analyses of these black Indian soils, but in the black Russian soils we have evidence, not only of their fertility, but also of the enormous stock of nitrogen which they contain, as also of the fact that the richness of nitrogen is limited to the depth of the black soil. The Bombay soil is celebrated for its fertility; who can doubt therefore that it has been, and probably still is, very rich in nitrogen?

With regard to the amount of exhaustion which is going on upon these Indian soils, it is by no means easy to form an estimate. According to Mr. Hunter, "Wheat land in the North-Western Provinces, which now gives only 840 lbs. an acre, yielded 1140 lbs. in the time of Akbar, and would be made to produce 1800 lbs. in East Norfolk." "Every one knows" (he also says) "that strictly scientific farming trebles the produce; that a field which produces 730 lbs. of wheat without manure can be made to yield 2342 lbs. by manure;" he further quotes the late Secretary to the Government of India in its department of Agriculture as declaring "that with proper manuring and proper tillage, every acre, broadly speaking, of land in the country can be made to yield 30, 50, or 70 per cent. more of every kind of crop than it at present produces; and with a fully corresponding increase of the profits of cultivation."

I have read Mr. Hunter's lecture with much pleasure, but trust he will forgive me for saying that had he been a little better acquainted with agriculture, he would not have made the comparison between the cultivation of the land as carried on in India, and in East Norfolk. The possibility of growing wheat crops with profit on the sandy soil of East Norfolk is due to the fact that a large amount of stock is kept in that district for which the farmer finds a ready sale at a high price, and to the facilities for procuring external sources of fertility, in the form of purchased cattle food and manure. Deprived of these advantages the Norfolk farmer would be more helpless than the Hindu.

Mr. Hunter feels some hesitation in adopting the statement of the late Secretary to the Government department of Agriculture, which I have quoted above, but believes that "without attempting any flights in scientific farming it is possible to steadily increase the Indian food supply to the extent of $1\frac{1}{2}$ per cent. per annum;" and he specifies four out of many considerations by which the produce of the soil may be increased. One of the impediments, he says, "to improved husbandry is the want of manure. If there were more stock there would be more manure."

Although stock necessarily produces manure, it by no means follows, under the peculiar condition of Indian agriculture, that an increase of stock would

increase the supply of human food. If in addition to his corn-bearing land, the Hindu had a considerable tract of waste land, where the animals could pick up a means of subsistence in the day, which would enable them to furnish milk and manure, the advantage would be obvious; but in those districts where dung is used as fuel, where one person has to get his living from an acre of land—which area includes swamps and waste—and in other districts where half an acre has to support an individual, it would probably be necessary to devote every inch of ground to the production of food for the family, and the consumption by stock of any part of the very limited supply might just make the difference between bare existence and starvation.

From a table given in the report of the Famine Commission it would appear probable that there is about nine-tenths of an acre in food crops to each head of the population, the other tenth being in what are described as non-food crops, such as indigo, cotton, hemp, tobacco, &c. The land yields about 10 bushels of corn per acre, principally millet or rice, 8 bushels of which are consumed, three-quarters of a bushel is used as seed, a rather less quantity as cattle food, 31 lbs. are allowed for waste, and rather more than 1 bushel is sold. The value of the produce raised is less than £2 per acre, upon which about 2s. per acre is paid as a tax to the Government.

With regard to the exhaustion of the Indian soils,

there can be little doubt that some decline in fertility is taking place ; also that, as population increases and more of the waste land is broken up and converted into tillage, this exhaustion will go on in an increasing ratio ; and however valuable irrigation may be as a means of bringing into action the resources of the soil, it must not be forgotten that unless the water contains the elements of fertility, either dissolved or suspended, it tends to diminish rather than increase the fertility contained in the soil.

It is true, no doubt, that where 1000 lbs. of grain are produced on an acre of land, and the bulk of this amount is consumed by the cultivator, the manure from both the corn and straw would for the most part find its way back to the land ; and even assuming that no external manures were derived from waste lands, this would so far reduce the exhaustion as to make the decline of the crop upon moderately fertile soils hardly perceptible, unless when taken over very lengthened periods of time. Still there must be exhaustion of the nitrogen of the soil; more especially in cases where we know that not only is the dung used as fuel, but also that saltpetre is manufactured from the drainage coming from the houses.

It would appear that the Indian cultivator has learnt how to extract the greatest possible amount of produce out of his soil, and neither the Norfolk farmer nor the scientific agriculturist—if restricted to such means as alone are available—could aid him

to produce better results. If however the Hindu could be taught that, while the demands upon the soil are increasing year by year, the produce of the soil, if not decreasing, is certainly not increasing, he will have learnt one important lesson which materially affects his welfare.

IRELAND.

When Ireland suffers from a deficiency of food, or from famine, the causes may be traced to the action of the climate, much in the same way as a similar cause produces a like effect in India. In each country the peculiar characteristics of the climate are occasionally intensified; excessive heat and drought produce famine in India; while too much moisture, combined with an absence of sunlight, produces scarcity and famine in Ireland.

In Great Britain, the United States, and in India, the cereal grains constitute the staple food of the population; while in Ireland potatoes are the main article of food.

Although the potato possesses in common with the cereal grain crops the property of producing large quantities of starch, it differs from them in several important points; it belongs to a different botanical order of plants, the starch is mainly stored up in its tubers instead of in the seed, and its growth extends all through the summer into the autumn, long after the ordinary cereal crops are harvested. The potato is

thus enabled to take up food from the soil at a period of the year when some of the more important manure ingredients are produced in the greatest abundance. The only cereal crop at all to be compared with it is maize, which likewise extends its growth into the autumn, and this probably is one of the reasons why the yield of maize in the United States is so much higher than the yield of the other cereal crops.

The potato further possesses the property of converting a very much larger portion of the manure ingredients of the soil into human food, than any of the cereal grain crops: for instance, to every bushel of wheat about 100 lbs. of straw are grown, while the haulm of the potato when dry is so light, that in our experiments we frequently do not think it worth while to weigh it. These properties, when combined with a suitable climate, enable the cultivator to produce, upon a given area of ground, a larger amount of human food from the potato than from any of the cereal grain crops.

In connection with these advantages, the potato, on the other hand, possesses the terrible disadvantage of being subject to disease to an extent unknown as regards the cereals.

Since 1848 statistics have been collected in Ireland which furnish us not only with the acreage under the various crops, but also with the average yield of each.

It will be interesting to examine these statistics for

the purpose of ascertaining whether they show any difference in the yield which might be attributed to a decline in the fertility of the soil. The statistics are only available from 1849, which would include a period of thirty-two years; as however the figures for 1880 are not yet published, and the favourable crops of that year would have tended to neutralise the bad crops of 1879, I have thought it fairer to exclude 1879 from the table and take the two periods of fifteen years, commencing with 1849 and ending 1878. The crops I have selected for examination are oats, potatoes, and flax; the results will be found in the following table:

TABLE.—*Showing the acreage, and average produce per acre, of oats, potatoes, and flax, on the average of two periods of fifteen years.*

	Oats.		Potatoes.		Flax.	
	Acreage.	Average yield.	Acreage.	Average yield.	Acreage.	Average yield.
		cwt.		tons.		stone, 14 lbs.
Average:						
1859–63 . .	2,058,544	12.96	1,011,214	4.15	128,309	33.01
1864–79 . .	1,605,867	12.74	974,372	3.32	178,981	25.87
Per cent. reduction during second period.	22	1.5	3.6	20	+39.5	21.6

In oats there has been a steady and continuous decline in the acreage grown in each period of five years from the commencement, while the average yield of the last fifteen years is only 1½ per cent. less

than that of the first period. In potatoes, the acreage grown is only slightly lower in the second period; there is, however, a very serious decline in the yield of the crop, amounting to 20 per cent., in the last fifteen years. In flax the acreage has been subject to some remarkable changes. Commencing in 1849 with 60,314 acres, it increased, with some slight interruptions, until it arrived at over 300,000 acres in 1864, but from that period it has steadily declined; still, the latter half of the thirty years shows an increase of acreage of 39½ per cent. over the first half. The decline in the yield of flax in the second period is very similar to the decline in the potatoes, amounting to 21½ per cent.

In two out of the three crops, we have a decline in the acreage during the latter period, while in all three there is also a decline in the yield per acre; the decline is very slight in the oats, but very considerable in the potatoes and flax. So far as the decline is due to exhaustion of the soil, we should expect to see it more marked in the potato and flax crops than in the oats, for, as I have already pointed out, the cereals, as compared with other crops, have a greater capacity for extracting food from an impoverished soil. The decline in the yield of the potato is accompanied with a decline in the area under cultivation; it cannot therefore be said that, owing to the increase in population, or some other causes, the cultivator has been compelled to extend his operations to soils having a

lower degree of fertility; the decline can only be ascribed to one of two causes, viz.: unfavourable seasons, or exhaustion of the soil.

The influence of weather upon the produce of the soil is one of the most complicated problems with which we have to deal: with regard to the seasons, each as compared with another has its own particular character, which is more or less favourable to the different crops that are grown.

In England, the year 1880 was very unfavourable to the wheat crop, while highly favourable both for barley and roots. If we were dealing with the wheat crop alone, so far as England is concerned, there would be very little doubt that a larger number of unfavourable seasons have occurred during the last period of fifteen years; but in Ireland, as regards the wheat crop, though there is a decline in the latter period, still, as it altogether does not amount to 5 per cent. the seasons can hardly be considered to have been specially unfavourable even to the growth of wheat, and the statistics for Ireland show no decline in the hay crop, and but a very small decline in the oat or barley crops, during the last period as compared with the first.

The large decline in flax and potatoes is exactly what we should expect to find if these two crops had been grown upon unmanured, or badly manured soils. While however a decline in the yield of potatoes might be looked for upon an impoverished soil, it by no

means follows that the produce would be more liable to disease. On the contrary, our experiments show that it is the highly manured potatoes which suffer the most from disease, and I think that the evidence given before the Potato Committee, by those engaged in the growth of this crop on a large scale, points to a similar conclusion.

While allowing therefore for a difference in seasons between the two periods, and that such difference is in favour of the former period, I am still disposed to think that the statistics indicate a certain decline of fertility in the soils of Ireland; and looking at the general character of the Irish soils, as well as the nature of the crops grown, this exhaustion might very probably be due to the removal from the soil of minerals, rather than of nitrogen.

CONCLUSION.

I will now proceed to sum up, and in some degree strengthen the evidence I have brought forward in the preceding pages in support of the views I have advanced with regard to the fertility and exhaustion of soils.

The Rothamsted experiments, at the present stage of their progress, indicate much more clearly than has hitherto been done, the line between the influence of the soil, and that of the atmosphere, in contributing the materials of which our crops are composed.

While I do not deny that plants may take up some carbon from the soil, and that they, or the soils in which they grow, obtain some combined nitrogen from atmospheric sources, still the results of the Rothamsted experiments relating to the chemical statistics of agricultural production, clearly show that the atmosphere is the main, if not the exclusive source of the carbon of our crops, and that the soil is the main, if not the exclusive source of their nitrogen.

With regard to the nitrogen, I would ask the following questions:—Is it possible by means of any crops, of any mechanical operations, or of any manures not containing nitrogen, to carry off more of the substance in the crops than is contained in the soil? And further, as the application of nitrogen by means of cattle-foods or manures is always attended by some loss—Can *as much* be recovered in the crops, as the sum of the amount brought on, and of that already existing in the soil?

The views of M. Georges Ville upon the subject of the sources of the nitrogen of our crops, as given in his book on "Artificial Manures," translated by Mr. Crookes, may be summed up as follows:—That crops always yield more nitrogen than is supplied in the manure; and that this excess is derived, not from the soil, but from the atmosphere. He points out, how small is the amount of combined nitrogen existing in the air as ammonia and nitric acid; that crops cannot

get more than about 5¼ lbs. of combined nitrogen per acre annually by rain; and that hence the source must be the free nitrogen of the air. He concludes—that leguminous plants, such as peas, beans, clover, trefoil, and lucerne, take practically the whole of their nitrogen from the air;—that others, such as beetroot and colza, require a certain amount to be supplied by manure, in order to establish active growth, but that after this they draw their supplies from the atmosphere; lastly, that others, such as the cereals, require the chief of their supply to be provided within the soil.

It will be observed that the facts I have adduced, and the conclusions I have drawn from them, are quite inconsistent with those put forward by M. Ville; and more especially those relating to the sources of the nitrogen of the leguminous and root crops.

I maintain that the amount of nitrogen supplied to our crops from the atmosphere,—whether as combined nitrogen brought down by rain, or that absorbed by the soil, or the plant,—constitutes but a very small proportion of the total amount they assimilate; and that the soil itself (or manure) is practically the main source of their supply. Indeed, it is a question whether, on arable land, as much or more may not be lost by drainage, or otherwise, than is supplied by the atmosphere.

It is not in the difference of their capacity for

taking up nitrogen from the atmosphere that we must look for an explanation of the distinctive influence, or function, so to speak, of the crops grown in a rotation. The explanation is rather to be found in the difference in the character and length of life of the different plants; in the character of the roots in regard to number, range, size, &c., and to their aptitude to derive more of their food and moisture from the surface, or from the subsoil; finally in the greater capacity of some for liberating and assimilating food not available to others, or for arresting food which would otherwise be washed out of the soil.

It will perhaps be said, that in maintaining the soil to be practically the source of the nitrogen in our crops—the leguminosæ and root crops as well as the cereals—we do away with the chief value derived from a rotation, viz. that of restoring fertility to the soil.

I admit that as a leguminous carries off much more nitrogen than a cereal crop, it is impossible to escape from the conclusion that the soil will be poorer in nitrogen after the removal of a leguminous than of a cereal crop. It is also a well-established fact, that a larger crop of wheat will be obtained after clover, which has removed a great deal of nitrogen, than after wheat, which has removed much less.

But the farmer has found by experience, and we have proved by direct experiment, that the roots, and other nitrogenous residue of a clover crop, may be

sufficient to supply all the nitrogen required by the succeeding corn crop. Indeed, it would appear from analyses that the surface soil of ordinary arable land may gain much *more* nitrogen by the growth of a clover crop than is required by the succeeding cereal crop. It may also be here observed, that the increase of 1 qr. of wheat and its straw, by the intervention of a clover crop, only represents an increased yield of nitrogen of some 12 to 14 lbs.

In the case of soils poor in accumulated or available nitrogen, the growth, and the after effect, of a clover or other leguminous crop, is less than in soils richer in available nitrogen.

In illustration of this fact, I may mention that in 1850 we took a crop of red clover from our continuously unmanured rotation experiment, and after an interval of twenty-four years, when we repeated the crop, the produce only amounted to about 1½ ton of hay, while the immediately succeeding wheat crop was even less than that obtained on a corresponding plot which had been under bare fallow instead of clover. In fact, taking the total six crops since the removal of the clover in 1874 (wheat, swedes, barley, beans, wheat, and swedes), the total amount of nitrogen removed from the unmanured clover plot, and from the unmanured fallow plot, was almost identical.

On the other hand, when a mixed manure, containing a liberal supply of nitrogen, had been applied, once every four years since the commencement of the

experiment, not only was the amount of clover hay, as also the amount of nitrogen removed in it, nearly three times as much as that on the unmanured plots, but the crops succeeding the removal of the heavy clover crops have been heavier, and have contained more nitrogen, than those from the similarly manured plot which was left fallow instead of being sown with clover.

Whatever may be the explanation of the well-established fact that, in ordinary agriculture, a wheat crop succeeding clover finds a more liberal supply of nitrogen in the soil available for its use, than where it succeeds another corn crop, the fact itself cannot, on due consideration of the various illustrations which have been given, be taken as any argument in favour of the assumption that the nitrogen of the clover crop was derived from the atmosphere.

The farmer only sees that there is an immediate beneficial effect produced on his wheat crop by the previous growth of clover; while science has established, that this is connected with an increased available supply of nitrogen in the soil for the wheat crop. But in these facts themselves, there is no evidence whatever whether the nitrogen of the clover crop was derived from the atmosphere or from the soil.

Nor can the United States farmer, who by the use of gypsum so largely increases his clover, as also the wheat crop which succeeds it, tell (any more than the

English farmer) from these facts, whether he has increased, or reduced, by from 100 lbs. to 200 lbs., the stock of many thousands of pounds of nitrogen which an acre of his soil contains within the range of the roots of the crops.

If we consider the well-established characteristics of the various leguminous crops grown in rotation, and the circumstances of their growth, it will be seen that their powers of taking up nitrogen, and of contributing to the increased growth of succeeding crops, are much in proportion to the length of their lives, and the range of their roots. Thus, everyone will admit that lucerne, sainfoin, and red clover, will grow larger crops without manure, and will leave a larger residue for the growth of succeeding crops, than either white clover or tares.

Again, if we follow the course of a barley and of a red clover crop, both sown nearly at the same time, it will be seen that when the barley has ripened its seed, the active growth of the clover has scarcely commenced, and the plant has still the latter part of the summer, the whole of the autumn, and to the autumn of the succeeding year, to collect its food. A man would consider himself very unfairly handicapped if he were required to do as much work in four months, as another was allowed eighteen months in which to perform it. After the cessation of the life of the barley, the formation of nitric acid in the soil is doubtless still active. In fact, direct

experiments show that the autumn drainage removes more nitrates than that of other periods of the year.

It is doubtless one of the economic functions of the clover plant to arrest and store up the nitrogen of the nitric acid in the soil, which would otherwise be drained away during the autumn and winter. Whether or not the leguminosæ may further take up any of their nitrogen directly from the nitrogenous organic matter within the soil, there is no direct evidence to show, though there are some facts which might be held to lend probability to the assumption.

When we see that the appearance of a fungus even on very poor grass land, is always accompanied by a rich growth of grass, we conclude that it has the property of liberating and utilising nitrogenous compounds in the soil which the grasses were unable of themselves to turn to account. It is at any rate not impossible that the leguminosæ may likewise derive at least a portion of their nitrogen from nitrogenous organic compounds within the soil; but their possession of green leaves may be taken as evidence that they derive the chief of their carbon from other sources than the organic carbon of the soil.

It is true that there are some known circumstances in connection with the growth of the leguminosæ which are not inconsistent with the idea that they derive their nitrogen from the atmosphere; and, if that view could be established as a fact, these cir-

cumstances would certainly receive a convenient explanation. Among them may be mentioned—the general indifference of such plants to a direct supply of nitrogen by manure; the benefit which they sometimes derive from the application of purely mineral manures; the increased amount of nitrogen in the surface soil after their growth; and the increased growth which they thus give to succeeding cereal crops.

But, on the other hand, the view in question entirely fails to explain—why those leguminous crops which take up the most nitrogen can be less frequently grown on the same soil; why we have entirely failed to grow clover successively on ordinary arable land, which was nevertheless in condition to yield fairly good corn crops; why the only condition under which we have been able to grow clover continuously, was where the soil was very much richer in nitrogen, as well as in other constituents, than the arable land; and lastly, why the growth under such circumstances has been accompanied by a rapid diminution in the amount of nitrogen in the soil.

It is quite true, that we have not been able clearly to establish by analysis that the subsoil of ordinary arable land, which has grown clover, is poorer in nitrogen than that of land which has been continuously under corn. When however we consider—that an acre of the Rothamsted arable soil taken to a depth of about 4 feet 6 inches contains about

10,000 lbs. of nitrogen; that different samples of subsoil from the same plot will vary somewhat from one another in their percentage of nitrogen; that only from 100 to 200 grains are submitted to analysis; and above all, that we can only repeat the growth of these deep-rooted crops at intervals of from eight to twelve years, it will be obvious, that to obtain absolutely certain experimental evidence on the point is, to say the least, extremely difficult.

It is, indeed, fortunate for agriculture, and also some consolation for the difficulties thus introduced into investigation, that the stock of nitrogen, even in a comparatively poor subsoil, is large enough to render the measurement of the losses to which it may be subject, only possible when the experiments are carried on over a very long series of years.

If the evidence of the Rothamsted experiments up to the present time has not established, beyond all cavil, that practically the source of the whole of the nitrogen in our crops is the store within the soil itself, and the nitrogenous manures brought upon it, there can be little doubt that in the course of their future progress they will afford conclusive evidence on this point.

At Rothamsted there are about twelve acres of land, distributed in six different fields, and under more than as many different crops, which have either been kept entirely without manure, or have only received purely mineral manures, for periods of from twenty-five to

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STAMFORD STREET AND CHARING CROSS.

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